Definition of requirements for an amateur radio payload in geostationary orbit

Preliminary proposal AMSAT-F with RAQI contribution

Contributors AMSAT-F : Thomas F4IWP, Jean-Marc F5LKE, Yannick F4HDA, Bernard F6CFO, Christian F1GWR, Loïc F4JXQ, Mathieu F4EZO, Guillaume F4DHK, Marie F4IKP, Yannick F4IQE, Christian F5UII, Christophe (AMSAT-F president)

Contributors RAQI : Benoît VE2VB, Gabriel VA2QA, Jean-François VE2ZDK, Glenn VE3XRA, Guy VE2XTD, Danny VE2VDG, Daniel VE2VDC, Roger VE2XM, David VA2DKK, Alan VE2NHR, Jacques VE2JVX, Pierre VE2PF, Olivier VA2DSF, Réal VE2DSK, Charles VE2FXO

Contact : groupe.travail.geo.esa@amsat-f.org

Summary

Geoscar is the response to a project by the ESA and consists of a transponder for geostationary satellites. This document, drafted by AMSAT-F with the collaboration of RAQI, specifies the needs of the amateur radio community and proposes avenues to address them. It primarily targets radio amateurs from ESA member countries in Europe and Canada but not exclusively. Amateur radio, by its nature, aims at individual instruction and technical study, thus sharing interests with the educational and research fields. Hence, the Geoscar project involves actors from these three communities, in addition to industrial players, in the design, development, and future use of the instrument.

The proposed solution must reconcile the needs of amateur radio operators, ease of use, the necessary reliability of a space system, and the innovation essential to the exploration of knowledge and technique. It takes into account constraints related to the platform, the space environment, and ground and user segments. Starting from a reliable hardware solution based on a linear transponder, several architecture, development, and utilization scenarios are described. Suggestions regarding platforms, project management, and financing are also discussed.

Contents

Summary 1
1. Introduction 3
2. Experience Feedback on QO-100 3
 2.1. QO-100 in Brief 3
 2.2. Lessons learned from QO-100 7
3. New Needs 8
4. Which longitude for which coverage 10
5. Proposed Solution 10
 5.1. Main Payload 10
 5.2. Consideration of the Educational Dimension 11
 5.3. Taking into account the innovation dimension 11
 5.4. Participatory Science 12
 5.5. Disaster Management and Alerts 13
 5.6. Ground Segment 13
6. Platform and Financing 14
7. Project Organization 14
8. Conclusion 15

1. Introduction

Amateur radio aims at individual instruction, intercommunication, and technical studies in the field of radioelectricity and radiocommunication. Based on these foundational principles, the amateur radio community has been highly active since the dawn of the space age, with the launch of the first amateur satellite OSCAR 1 on December 12, 1961, surpassing many space nations. The amateur radio community has contributed, among other achievements:

- the in-flight qualification of the first CMOS chip,
- the first Doppler shift analysis to locate ground beacons leading to the COSPAS-SARSAT Search and Rescue system,
- the first inter-satellite communication link,
- the demonstration of the first GPS receiver in high elliptical orbit,
- the development of packet transmission protocols still used in many commercial systems,
- the utilization of CubeSats,
- the design of the first DVB-S2 transmitter in Ka-band for small satellites,
- the operation of the world's largest distributed ground segment, pioneering Ground station-as-a-Service offerings that are now commercially available.

More recently, the launch of the geostationary satellite Es'hail 2 in 2018, a Qatari telecommunication satellite, carrying the QO-100 amateur radio transponder on board, enabled reaching a large number of radio amateurs in Europe, Africa, the Middle East, and parts of Asia and South America, thanks to extensive coverage and the use of commercial hardware.

The European Space Agency's proposal to carry an amateur radio payload on a future geostationary mission presents a unique opportunity that paves the way for a global amateur radio satellite network and meets the needs not only of radio amateurs but also educational, scientific, and industrial interests.

This preliminary document offers a feedback of QO-100 (section 2), specifies the needs of users, whether amateur radio operators or academics (section 3). The issue of coverage is then addressed (section 4). A proposal for a modular solution, with increasingly complex drawers, is discussed in relation to user needs (section 5). Platform and financing considerations are addressed (section 6). A summary of the proposal is provided as a conclusion (section 6).

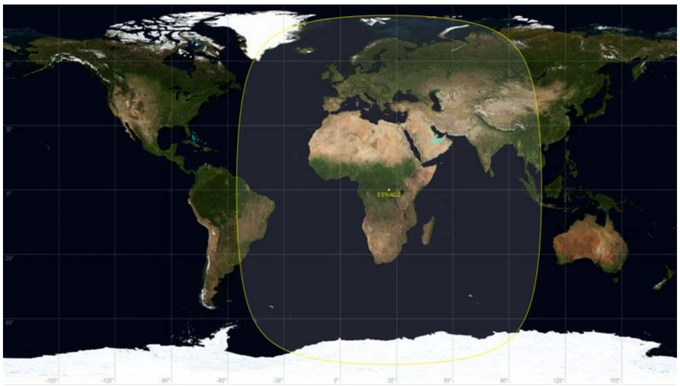
2. Experience Feedback on QO-100

2.1. QO-100 in Brief

(Sources: https://on5vl.org/qo-100/, https://amsat-dl.org/en/new-qo-100-band-plan/, https://eshail.batc.org.uk/wb/)

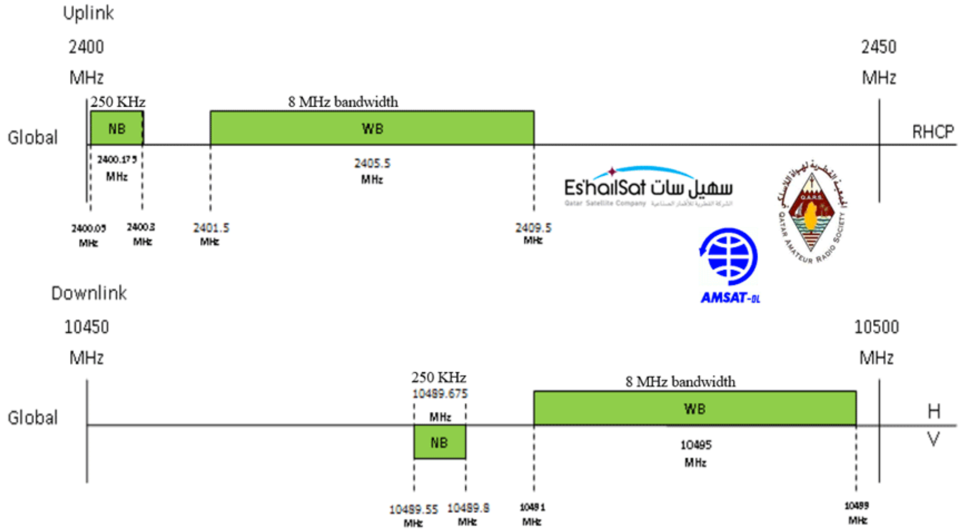
The Space Segment

Es'hail 2 (or Qatar-OSCAR 100 or QO-100) is a Qatari satellite launched on November 15, 2018. It operates from a geostationary orbit at 26° East longitude and provides television services for the Middle East and North Africa. It features a dedicated transponder for amateur radio service, making QO-100 the first amateur radio GEO satellite.



The amateur radio payload consists of:

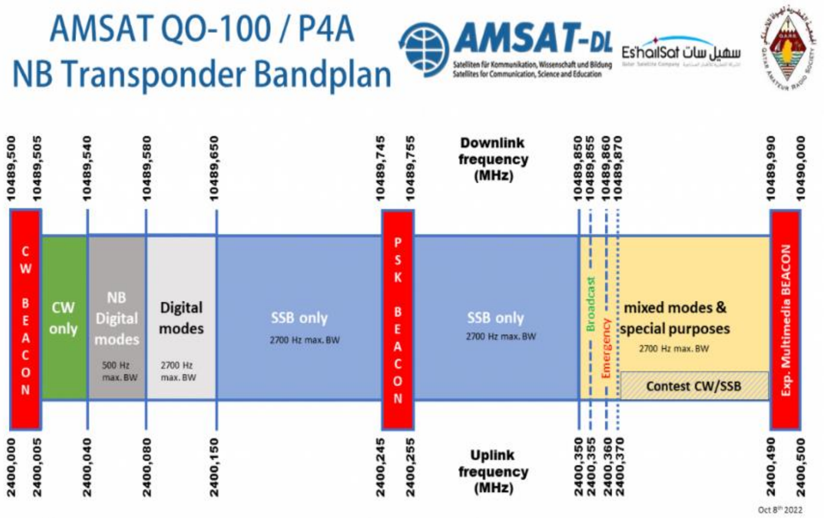
- Two linear transponders adapted from commercial TV transponders, one narrow-band of 500kHz and the other wide-band of 9MHz.
- For reception, a circularly polarized right-hand feed horn antenna in the S-band.
- For transmission, a vertically polarized feed horn antenna in the X-band with a peak power of 100W.



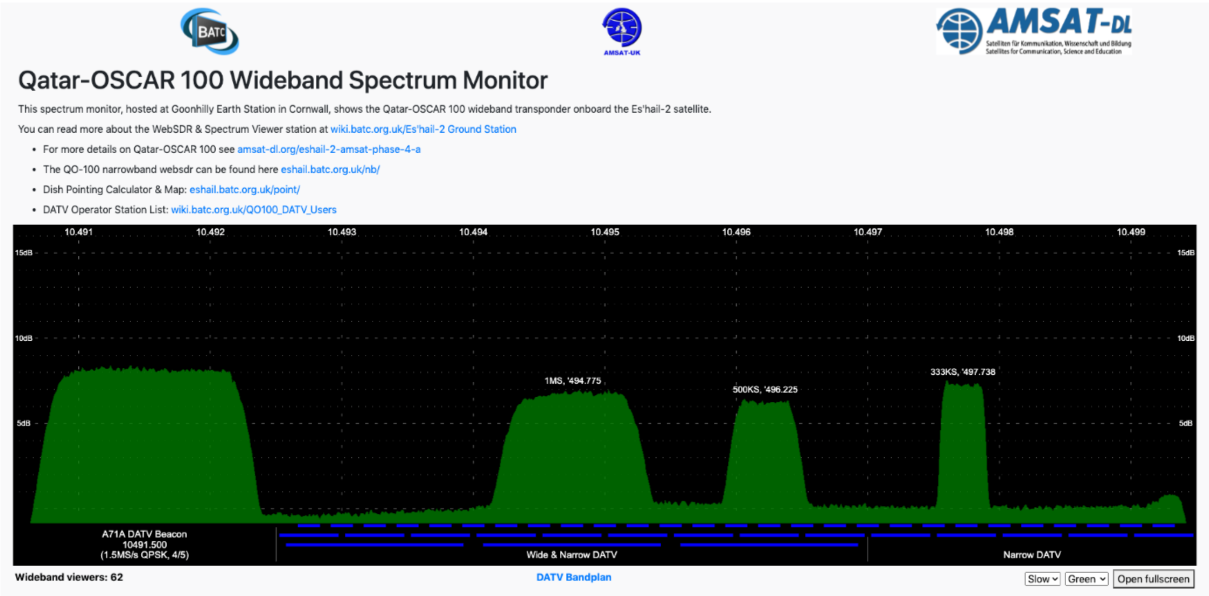
-

Xpdr	U/L FREQUENCY (MHz)				D/L FREQUENCY (MHz)				LO	BW
No	Pol	Begin	Center	End	Pol	Begin	Center	End	(MHz)	(MHz)
NB	RHCP	2400.05	2400.175	2400.3	V	10489.55	10489.675	10489.8	8089.5	0.25
WB	RHCP	2401.5	2405.5	2409.5	H	10491	10495	10499	8089.5	8

The Narrow Band transponder's frequency plan of QO-100 extends from 2400.000 MHz (10489.500) to 2400.500 MHz (10490.000) on the uplink (downlink) and is detailed in the following figure:



The Wide Band part extends from 2401.500 MHz (10491.000) to 2409.500 MHz (10499.000) on the uplink (downlink). It's noteworthy that for the Wide Band downlink, the polarization is vertical.



The available modes on QO-100 (SSB/CW, FreeDV, RTTY, PSK31, FT8, ROS, FAX, SSTV, KG-STV, Ea-sypal, DATV DVB-S2) allow for voice communication and image transmission, in digital and/or analog format. Three beacons at the beginning, middle, and end of the band help synchronize ground stations. The transponder also features an SSB channel reserved for emergencies: 2400.360 MHz on the uplink, 10,489.860 MHz on the downlink.

The Ground Segment

The ground segment consists of 2 sites:

- The first site in Bochum, Germany, equipped with a 3m antenna for the uplink and a 2.5m antenna for the downlink. It is managed by AMSAT-DL and oversees the beacons and the Leila logic of the Narrow-band transponder.
- The second site is located near Doha, Qatar, at the Es'hailSat Satellite Control Center, with a 2.4m S-band antenna for the uplink. It hosts the wide-band beacon. Both sites provide redundancy to each other. The ground segment generates the beacons relayed by the transponder and provides a reference for users. The LEILA and LEILA-2 systems provide a power indicator not to exceed and monitor the spectrum.

The User Segment

The bands used by the QO-100 transponder, S-band (2.4 GHz) for the uplink, and X-band (10 GHz) for the downlink, allow users to easily adapt commercial equipment to operate via QO-100. The reception and transmission parts are independent. It's also important to distinguish between the use of narrow-band (voice and digital modes) and wide-band emission (DATV). The equipment needed for narrow-band is relatively simple; typical equipment consists of:

- A satellite dish, a PLL LNB, a T-Bias, an RTL-SDR dongle, and a computer equipped with SDR software (often SDR Console, freeware) for reception.
- A computer, a transmitter generating signals at 2.4 GHz, an amplifier, a helical antenna, and a satellite dish for transmission.

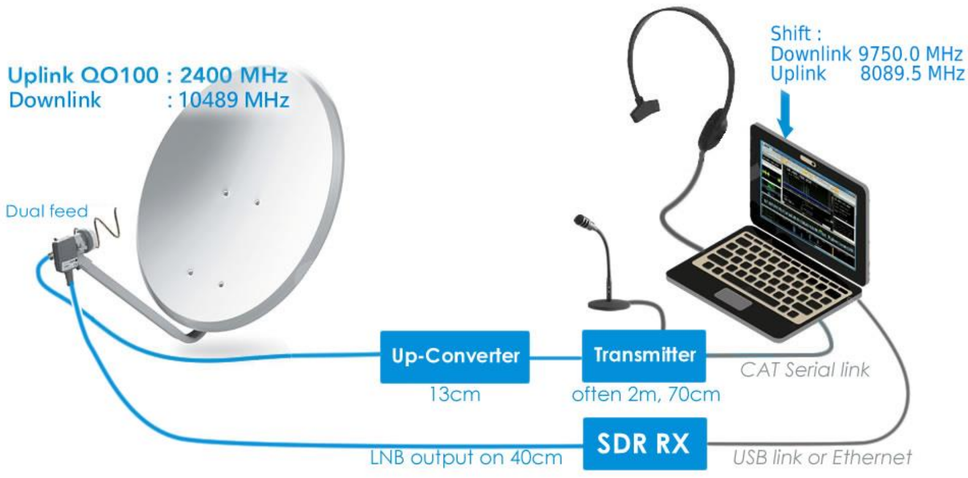
Both in reception and transmission, the equipment used must be very frequency-stable, requiring the use of GPSDO (GPS-disciplined oscillator).

For implementation, various approaches are possible:

- Dish diameter between 0.6 and 1.2 m
- For transmission:
  > 1st approach: analog technology including a VHF or UHF transceiver followed by a mixer driven by a GPSDO + an amplifier delivering power between 3 W and 20 W
  > 2nd solution: digital technology based on an SDR module (for example Adalm Pluto manufactured by Analog Device). This module must be followed by a preamplifier before driving the amplifier.

- Antenna: patch (Poty antenna), helical, etc.

A possible station configuration is detailed on the following website: https://www.f5uii.net/control-transceiver-upconvert-with-serial-port-sdr-console-satellite-qo100-eshail2/



The description above concerns the use of QO-100 for voice communication (narrow-band). Implementation is within the reach of a moderately experienced amateur radio operator.

Transmission in DATV (Wide Band) requires more significant resources and increased technical skill. The architecture is similar to that for voice communication, but with modules adapted to the specifics of DATV. This includes the use of a reception module such as "Minitioune". For transmission, an Adalm Pluto module is used along with various software (OBS, etc.). The transmission power must be higher (between 30 and 100W), and the dish diameter between 1 and 1.3m.

2.2. Lessons learned from QO-100

After more than 5 years of QO-100 usage, several insights can be drawn:

> QO-100's success lies in its accessibility to a wide range of users. This implies that operators should have relatively easy-to-use equipment. The choice of an uplink at 2.4GHz and a downlink at 10GHz facilitates this accessibility by allowing users to adapt readily available commercial equipment intended for Wi-Fi and satellite television applications.

> Complexity management is ensured on the ground through the ground segment with stations in Doha and Bochum, which transmit the beacons for proper calibration of operators' stations and manage some flow regulation. The agnosticism of the linear transponder allows for the use of various modes, the implementation of which is facilitated by software and hardware developments made by users.

> From a technical standpoint, the linearity of the transponder is crucial and represents a particular area of vigilance for the development of future payloads.

> In terms of usage:
- The number of narrow-band channels is largely sufficient in the current context and considering the covered area, meeting expectations.
- With a bandwidth of 8MHz, the wide-band portion is quickly limited and should be expanded (perhaps to 16 MHz).
- Two functionalities appear useful: an alert system for exceeding power limits (a DATV-adapted

Leila type) and a "anti-chatter" system to limit permanent channel occupation by emitting a fixed pattern.

> QO-100 serves as a valuable communication vector for broadcasting amateur radio community events. It has been used for broadcasting amateur radio conferences (e.g., RSR Amsat-F) and relaying ARISS contacts.

> QO-100 also serves educational purposes, facilitating contacts between schools from different countries or between schools and scientific expeditions/stations.

> It's important to note that while the specifications for QO-100 were made by AMSAT-DL, the main contracting was carried out by Mitsubishi, with funding from Qatar. Es'Hail-2, which hosts the QO-100 amateur transponders, is not exclusively dedicated to radio amateurs but serves other purposes and needs as well. Thus, any new payload proposal must consider these aspects, which bring constraints and compromises.

3. New Needs

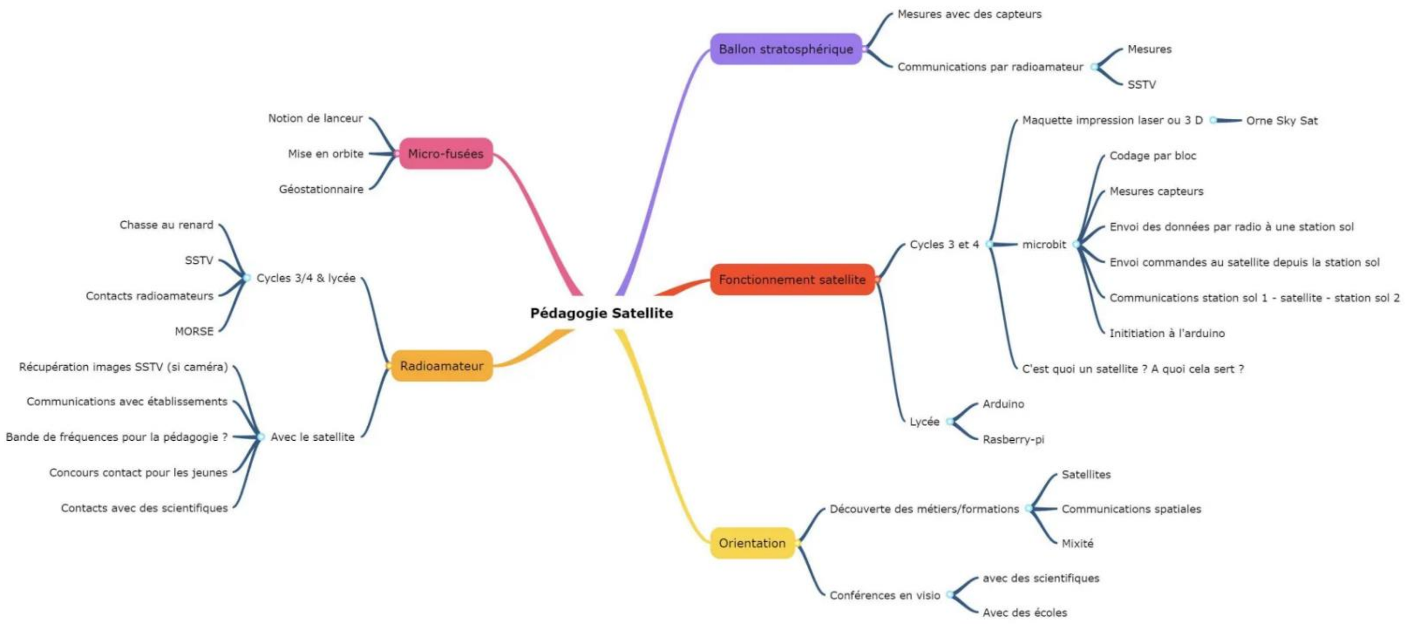
To meet the needs and continue engaging radio amateurs, it is pertinent to build on the success of QO-100 and expand its offerings. This includes leveraging the equipment that radio amateurs have already implemented, fostering synergies between future satellites and QO-100, which is expected to operate until 2034, by connecting more people through expanded coverage and imagining new uses.

Through this project, there is an identified essential need to address the educational community, students, and learners of all ages. The educational purpose of amateur radio should be embodied in the future payload to initiate new generations into technology, science, and citizenship. This includes:

- Initiating and engaging primary to high school students in scientific and technical questions through various projects: communication, image transmission, scientific measurements, conferences, scientific concepts, and ground system development: maps, stations, programs.

- Attracting and training future engineers for space and telecommunications fields, which are currently facing a shortage of skilled labor (risk of knowledge loss with future retirements).

The following figure, from the AMSAT-F Amateur Radio Education Working Group, illustrates the strong interest of the educational community in space. The role of radio amateurs is key in initiating and training in the space domain through communications and other applications, project logistics, and tool mastery.



In addition to telecommunications, Earth observation and space meteorology are applications that address societal challenges related to climate change and increasing use of outer space.

To continue innovating, it is necessary for the proposed payload to not just be another QO-100 but to present an original challenge for at least part of the amateur radio community, such as exploring millimeter-wave bands at 24, 47, and 77 GHz, knowing that the latter two bands pose numerous difficulties, or optical communications, subject to consensus agreements with ICAO and the military, which are currently underutilized. Their exploitation requires the development of solutions for both the space and ground segments. In doing so, the amateur radio community could collaborate with universities and research laboratories that can mobilize dedicated resources. CubeSat programs already demonstrate a close connection between universities and radio amateurs through university space centers, which represent a major entry point for new radio amateurs.

The educational and innovation aspects require establishing links with the academic world through interfaces such as ARISS[1], Planète Sciences[2], and University Space Centers[3]. Projects such as the connection between Crozet[4] and classes in mainland France via QO-100 illustrate the significant interest in a GEO amateur radio payload.

With its wide coverage, a payload in geostationary orbit could be an important tool for responding to emergency situations related to extreme weather events and contribute to the Cospas-Sarsat system and other alert systems.

Beyond these primary needs, an amateur radio payload in geostationary orbit is an opportunity to develop the Hamnet network (an isolated IPv4 amateur network from the Internet), providing low-bandwidth access to the Hamnet network for remote sites. This alternative internet network represents an attractive opportunity to expand the user community.

With the emergence of New Space, amateur radio CubeSats, especially those led by university space centers, have multiplied. Proposing a relay for inter-satellite connections, especially LEO/GEO, would structure a data recovery network. Interconnections with AMSAT/SatNogs networks would further enhance the appeal for amateur radio CubeSats.

[1] https://www.ariss-f.org/

[2] https://www.planete-sciences.org/national/

[3] https://www.enseignementsup-recherche.gouv.fr/fr/les-centres-spatiaux-universitaires-csu-46382

[4] https://crozet2022.r-e-f.org

4. Which longitude for which coverage

Due to the longitudinal extent of the ESA member countries, from Eastern Europe to Western Canada, it is not possible to have a geostationary position that covers all citizens. The longitude of the future satellite must be the subject of discussions and compromises. In their proposals, AMSAT-UK[1] and AMSAT-DL[2] examine various scenarios for the location of the future satellite. Among other aspects to consider, there is the commercial interest of the satellite carrying the amateur radio payload, or the possibility of establishing a ground relay between QO-100 and the future satellite, which would shift the satellite further westward.

[1] https://www.amsat.org/wordpress/wp-content/uploads/2023/12/ESA-GEO-proposal-AMSAT-UK.pdf

[2] https://amsat-dl.org/en/the-next-generation-of-a-geo-meo-amateur-radio-payload/

5. Proposed Solution

The proposed solution can be broken down into distinct and modular elements, which, depending on the chosen solution, can be integrated into a single payload. It is a "drawer" solution where additional complexity elements can be considered based on constraints and financing.

5.1. Main Payload

The main element of the payload consists of a narrow-band and wide-band linear transponder. It is based on a commercial solution like QO-100. The uplink is at 2.4GHz and the downlink is at 10GHz. Its main characteristics are reliability and linearity.

The primary objective of this element is to provide a versatile tool to a large number of radio amateurs (reuse of equipment). The transponder is agnostic regarding its use and should allow for usage innovations such as the development of Hamnet using the NPR-VSAT protocol.

A secondary objective is to establish a link with QO-100 via a ground station on a dedicated channel (mode and bandwidth to be defined). This station would relay communications from both satellites on a dedicated channel to strive for global coverage.

Particular attention must be paid to reliability and linearity.

Several levels of complexity can be envisaged:
- At level 0, a wide-beam antenna is used to illuminate the entire surface.
- At level 1, directional antennas can be considered to improve link balance in inhabited areas.

5.2. Consideration of the Educational Dimension

In the context of activities with schools, image broadcasting is very attractive and can engage students. Thus, a high-resolution camera broadcasting Earth images on a dedicated channel (in SSTV, DATV, etc.) can meet this educational dimension. Several levels of complexity can be imagined.
- At level 0, the transponder retransmits images sent from ground stations.
- At level 1, a camera is onboard.

The educational objectives are multiple:
- Reception/decoding of an analog signal (possibly digital?)
- Introduction to meteorology and climate studies

Educational Experience: The Crozet Project

In 2022, following the model of school-to-International Space Station (ISS) connections, the French Southern and Antarctic Lands (TAAF) and the French Amateur Radio Association (REF, an association of French radio amateurs) offered schools (primary schools, middle schools, high schools, universities, etc.) the opportunity to connect, via the QO100 satellite link, with scientists based in the Crozet archipelago, located in the southern Indian Ocean.

Interested schools, in collaboration with radio amateurs, were required to submit a dossier describing the educational activity planned as part of the project. A selection made by AMSAT Francophone in November 2022 chose sixteen schools. As an example, the Lyon F8KLY radio club enabled students from three schools in the Lyon region to participate in this project. The schools involved were: René Descartes High School in Saint Genis Laval (3 classes of sophomores), Saint Thomas d'Aquin Middle School in Mormant (2 classes of 6th graders), and Marie Curie Primary School in Oullins (CM1-CM2 class).

The experience captivated both students and teachers: https://f8kly.fr/crozet/

In the context described above, more than 120 students participated in the Crozet 2023 project via QO100.

5.3. Taking into account the innovation dimension

For this component of the payload, the goal is to develop a solution that allows the use of millimeter wave bands at 24, 47, and/or 77 GHz. Experimentation is at the heart of the amateur radio community, and while only a few enthusiasts and experts in the community currently master the millimeter wave bands, collaboration with universities could be a real opportunity to accelerate the skill development of radio amateurs and the evolution of knowledge.

Alternatively, optical communications are currently experiencing significant interest, and a proposal can be made in this direction. The module developed must take into account both the ground and user segments. On the ground side, commercial mixers exist to upconvert the frequency(https://www.hasco-inc.com/mmwave-mixers.html) .

As a technological demonstrator, its operation should remain simple, with the challenge lying in the technical/technological aspect.

Note
We are aware of the difficulty involved in the frequency upconversion. Equipment is difficult to obtain and/or expensive. This is particularly true for the transmission part, where radio amateurs would need to equip themselves or develop specific equipment to ensure that the transmission chain complies with regulations. A more accessible approach would be to consider only ground reception.

5.4. Participatory Science

Due to its geostationary position, the payload is ideal for collecting and transmitting to the ground information from IoT sensors.

The objectives are both educational and experimental.

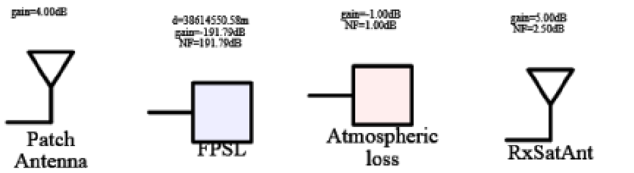
The difficulty lies in the low link budget for ground devices with limited power. A preliminary estimation of the link budget considering a 2.4 GHz patch antenna on the ground suggests achievable data rates of 100 bits/s.

Alternatively, a LoRa solution at 433 MHz developed for CubeSats in low Earth orbit and tested on a stratospheric balloon can be considered.

RF budget with properties

Elements:	[1x4 rf.internal.rfbudget.Element]
InputFrequency	2400000000.0 Hz
AvailableInputPower	30.0 dBm
SignalBandwidth	2500.0 Hz
Solver	Friis

Analysis Results



ThermalNoise:	(dBm)	-136.99			
OutputFrequency:	(Hz)	2400000000.00	2400000000.00	2400000000.00	2400000000.00
OutputPower:	(dBm)	34.00	-157.79	-158.79	-153.79
TransducerGain:	(dB)	4.00	-187.79	-188.79	-183.79
Noisefigure:	(dB)	0.00	187.79	188.79	191.29
SNR:	(dB)	166.99	-20.80	-21.80	-24.30
ChannelCapacity:	(bps)	138680.14	29.86	23.74	13.37

5.5. Disaster Management and Alerts

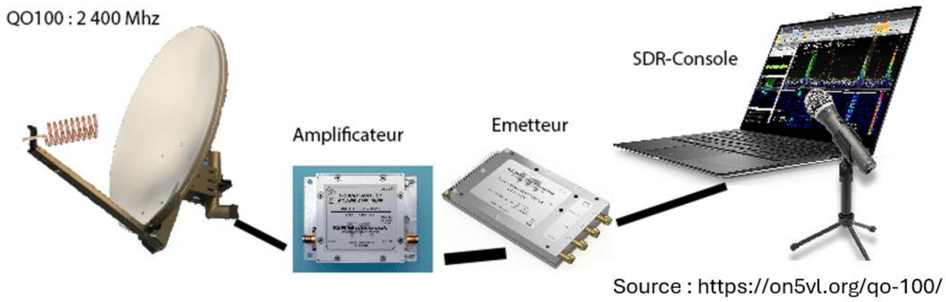
To contribute to the resilience of telecommunication systems and meet the needs in disaster situations, the payload must have dedicated channels for emergencies. The system can also rely on the IoT part of the payload. A band should be reserved for emergencies, similar to QO-100 for voice communication. Thanks to the flexibility of the linear transponder, all current and future modulation and coding modes of emergency services can be used, with data rates approaching Mb/s, which will facilitate its deployment.

5.6. Ground Segment

Two parts are to be distinguished at the ground segment level: the control segment and the user segment. The ground segment model follows that of QO-100.

For the control segment, the first station would be installed in Europe, and the second in Canada (Quebec?) or South America (Guyana?). The station in Europe would be the main station, with the station outside Europe providing delegation of certain functions (TBD) and redundancy for the first station in case of failure.

As for the user segment, since the main payload would consist of a linear transponder similar to QO-100 and operating on the same bands, the reception and transmission chains have the same scheme as represented in the following figure (RX at the top, TX at the bottom).



Regarding the other modules considered, the developments to be made for the user segment are still to be defined.

6. Platform and Financing

In the call for projects, the amateur radio payload is a secondary payload of a larger system such as a telecommunication satellite for QO-100. It must therefore comply with the platform specifications.

Several financing options are being considered:
- Industrial partnership
- Public funding (France 2030 for the innovation part, etc.)
- Appeal for sponsorship
- Insurers for risk management
- European funds

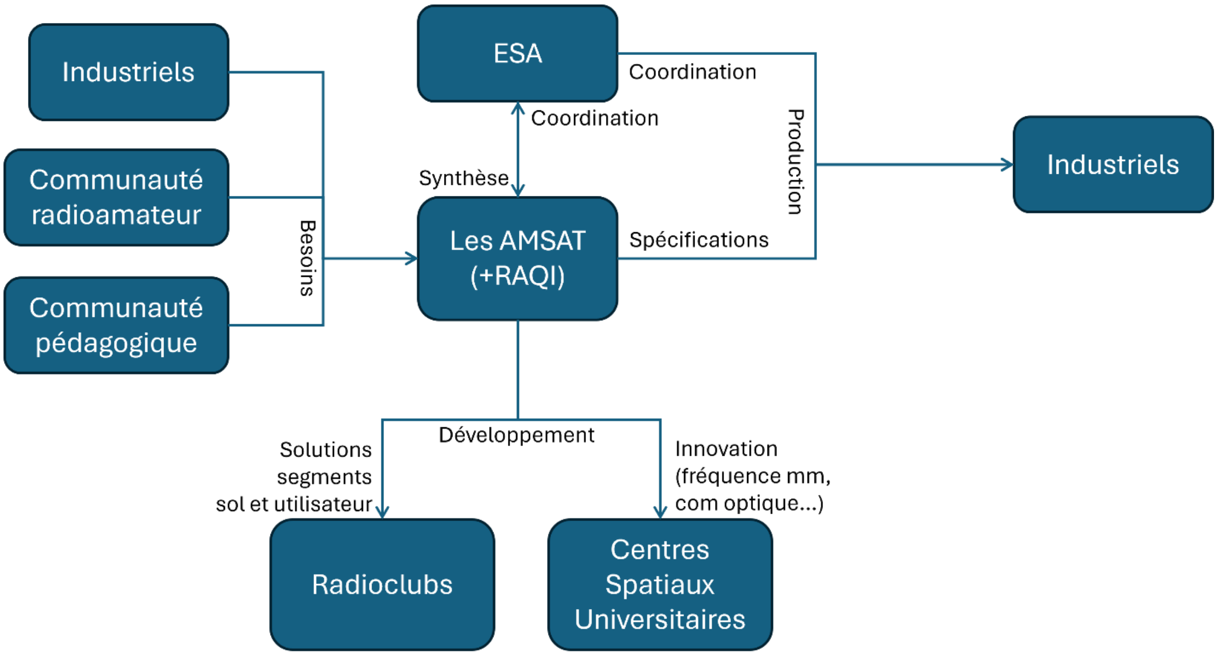
7. Project Organization

To successfully carry out the project, we propose the following organization:

- ESA ensures the coordination of the main actors in design and production.
- AMSAT (+RAQI) handles the design of the payload through the collection of needs, their synthesis, in their specification, and the development of innovative solutions.
- The amateur radio and educational communities and industries define their needs.

- Radio clubs and radio amateurs are responsible for the development of hardware and software solutions for the user and ground segments.
- University Space Centers with radio amateurs wishing to develop their skills are responsible for the development of the innovative part of the payload through their privileged links with laboratories and universities and engineering schools.
- Industries ensure the realization of the payload's flight model.

The following figure illustrates the proposed organization:



8. Conclusion

Geoscar is the proposal for the amateur radio payload of AMSAT-F (+RAQI?). It consists of a "drawer" solution to meet the needs of radio amateurs, educational purposes, and innovation. The solution is based on a main element, which is a linear transponder adapted from commercial sources with an uplink at 2.4 GHz and a downlink at 10 GHz, similar to QO-100. Specific modules such as a high-resolution camera for educational aspects, a card for millimeter wave bands (or optical communication) for technological innovation. The payload will also be able to respond to usage innovations (Hamnet, IoT) and contribute to participatory science. Finally, the payload must meet the needs related to disaster management and alerts.